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LHC BB Workshop

K. Yokoya

STRONG-STRONG WORKING GROUP

SUMMARY

- Coherent BB mode
  - Summary of theory
    higher modes, mode couplings, feedbacks,
  - Tune difference
- Strong-strong simulation technics
  CBI, FMM
- Parasitic crossing problems
  COD
  Coherent modes

Coherent Beam-Beam Modes

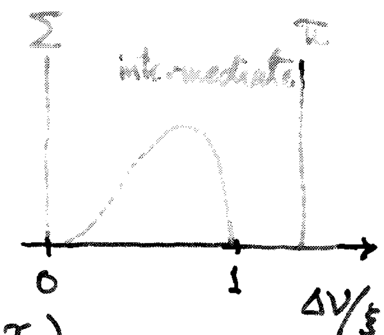
Summary of theory

(Most progress by Alexahin)

- The simplest case

  single-bunch , equal parameter , dipole

  $\Delta\nu_\pi = (1.21 \sim 1.33)\,\xi$



  Higher radial modes

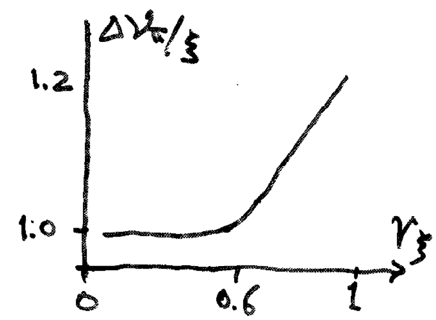
  $\Delta\nu_\pi / \xi = 1.026 ,\ 1.002$ (flat beam x)

  (radial ----- in the phase space (x, x'))

- Unequal intensity

  Strong-strong ⟷ weak-strong

  $r_\xi \equiv \dfrac{\xi_{weak}}{\xi_{strong}} \approx 0.6$



  $r_\xi \lesssim 0.6$

  → π mode frequency merges into the continuum.

  (Confirmed by flat beam simulation (Hirata et al))

- Include synchrotron oscillation, crossing angle, IP offset, IP dispersion, ---

- Responce to feedback system

  BPM errors excite continuum.

  $\longrightarrow$ emittance growth.

$$\frac{1}{\varepsilon_0}\frac{d\varepsilon_x}{dN} \approx \underbrace{\frac{1-C_0^2}{4}}_{\text{dipole kick} \Rightarrow \pi \text{ mode}} \frac{g^2 \Delta_{BPM}^2}{\left(1+\frac{g}{2\pi|\xi|}\right)^2}$$

normalized.

$\xi = 0.01$
low gain $g = 0.2$
8 hours ($N = 3.2 \times 10^8$)

$\Rightarrow$ $\Delta_{BPM} \lesssim 1\,\mu m$ ($\beta_{BPM} = 200 m$)
for $\Delta\varepsilon_x/\varepsilon_0 < 1$

- Quadrupole, sextupole, --- modes
  ↑ in phase space

  $\lambda_\pi(\text{quad}) = 1.026$
  $\lambda_\pi(\text{sext}) = 1.002$
  } same as radial modes? by chance?

- Mode Coupling

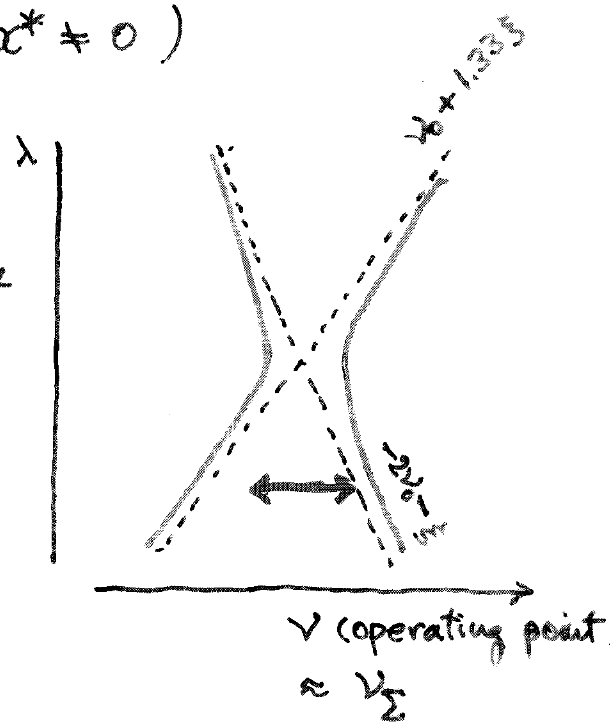
  $e^{im_1\phi}$, $e^{im_2\phi}$ can couple.
  (only $m_1 - m_2 =$ even for symmetric case)

  e.g. coupling between $e^{im\phi}$ and $e^{-im\phi}$
  causes stop band near $\nu =$ integer$/m$

  Phenomena observed at LEP
  might be due to mode coupling

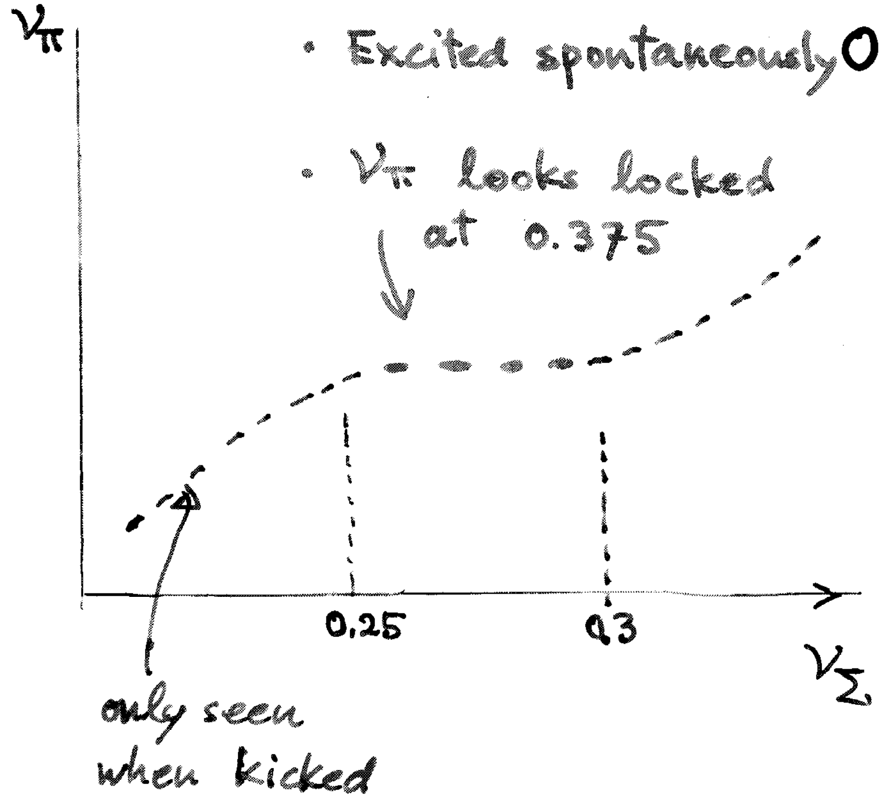
  - Observed at dipole $\longrightarrow$ $m_1 = 1$
  - The lowest coupling with $m_2 = 2$
    (can couple if $\Delta x^* \neq 0$)

  Can explain the
  instability in a limited range



Observation at LEP

(Cornelis)



Yuri's guess

Coefficient close to 1.0

$$\nu_0 + 1.33\,\xi = \text{integer} - 2\nu_0 - \xi$$

$$\Rightarrow \quad \nu_0 = 0.287 \qquad (\xi = 0.06)$$

$$\nu_\pi = \nu_0 + 1.33\,\xi = 0.367$$

not far from 0.375

To be studied further at LEP.

Good topic for coherent mode theory.

Tune Difference (Hofmann)

$$\begin{cases} \nu_\Sigma = \nu_0 \\ \nu_\pi = \nu_0 + 1.3\,\xi \end{cases}$$

$\nu_1^0 = \nu_2^0 = \nu_0$ operating point

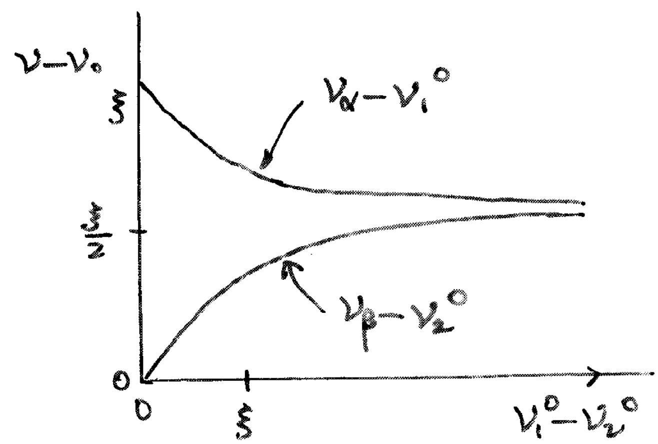
$$\begin{cases} \nu_\alpha = \nu_1^0 + \frac{1}{2}\xi \\ \nu_\beta = \nu_2^0 + \frac{1}{2}\xi \end{cases}$$

$|\nu_1^0 - \nu_2^0| \gg \xi$

Observation at

SPEAR 1974

PEP II



Two beams can be decoupled if $|\nu_1^0 - \nu_2^0| \gg \xi$.

Collision is stable
if two beams are stable individually.

Non-rigid beam theory not done yet
but can be done.

Requires 2 working points

Strong-Strong Simulation Methods

- CBI (Krishnagopal)

PIC with 2D Cartesian grid

Upto now,

1 bunch / beam

longitudinal motion not included

crossing angle not included

Results for LHC

no emittance growth at nominal bunch current (0.2mA)

beamsize growth ~ 1~2% / 10^5 turns at 1mA

(dipole effects artificially suppressed)

Very small computing noise

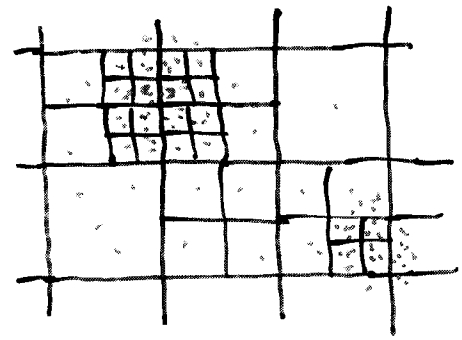
($\ll$ 1% / 10^5 turns with 10^4 macroparticles 125 × 125 grid)

As a tool for LHC,

A few bunches × $\underbrace{10^5 \text{ turn}}_{\sim 10 \text{ sec}}$ can be tracked

Fast Multipole Method

- **FMM algorithm** (Dyachkov)



  - Fine mesh in densely populated region
    → computation efficiency.
  - Use multipole expansion for the force from distant grid points

Best suited for parasitic collision

Computing time

perhaps, comparable to CBI for head-on.

Problems Related to Parasitic Crossing

Parasitic crossing dominates over head on at LHC.

New situation compared with LEP, PEP II, HERA ....

COD

Parasitic crossing causes COD differences between bunches.

Major effects ..... Δx^*, Δy^*

- How large $0.1 \sim 0.2\ \sigma$ expected.

  More accurate values can be computed by
  - tracking all bunches (as rigid particles)
  - with Gaussian B.B. force (assumed beam size)
  - with strong, artificial damping

- Tolerance of $\Delta x^*, \Delta y^*$

  - HERA simulation of random error (e.g. seismic motion, power ripple)

    $\Rightarrow \sim 0.2\sigma$ (proton beam life)

    $\xi = O(10^{-3})$

  May be tighter for LHC?

Lowest order in LHC footprint

- 13-th order resonance strength

  Compare with the crossing angle.

  $$\frac{\alpha}{2} = 150 \ \mu\text{rad} \iff \Delta x^* = 0.85\,\sigma$$

  (Lennissen)

  (13th order information extracted from tracking simulation)

  $\Rightarrow$ $\Delta x^* = 0.1 \sim 0.2\,\sigma$ is safe
  if $\alpha/2 = 150 \ \mu\text{rad}$ is OK.
  <u>if</u> 13-th order is the issue.

- Effects on the coherent mode?

- Reliable tolerance not known

  Main result ---- proton life time.

  Tracking simulation hard........

  John Irwin's algorithm?

Experiment

- Must be hadron machine

- 1 bunch + 1 bunch
  with artificiall offset will be enough.

- But theory for parameter scaling needed.

- Measurement of $\Delta x^*, \Delta y^*$

Can be done by luminosity monitor
down to $\sim 0.1\,\sigma$

Requirement to monitor ⊛
Must resolve bunch collision!

(present plan 10 bunches → 1 bunch
not very expensive)

What can be measured is $\mathcal{L}_{bunch}$.

$\mathcal{L}_i < \mathcal{L}_0$ may not be due to $\Delta x^*, \Delta y^*$
can be beamsize growth

But still the information is precious.

⊛ $\Delta x^*, \Delta y^*$, transverse profile
may be obtained by other way
(synch. light monitor)

Fast luminosity monitor really needed?

Beam-Beam Modes under Parasitic Collision

- Simulation (Herr)
  - Old LHC parameters
  - 256 bunches. (Due to computer power)
  - Rigid bunch
  - Ignore COD (use $F(x) - F(x_0)$)

Results

- Coherent dipole can be excited
- Non-linear resonance (3rd order) seen.

  Limits $\xi_{max} \approx 0.008$
  (nominal 0.0034 at that time)

- Strong decoherence effect if $\Delta\nu \sim 10^{-5}$ added.
  due to many long-range kicks, with
  many different phases.

Has to be revised

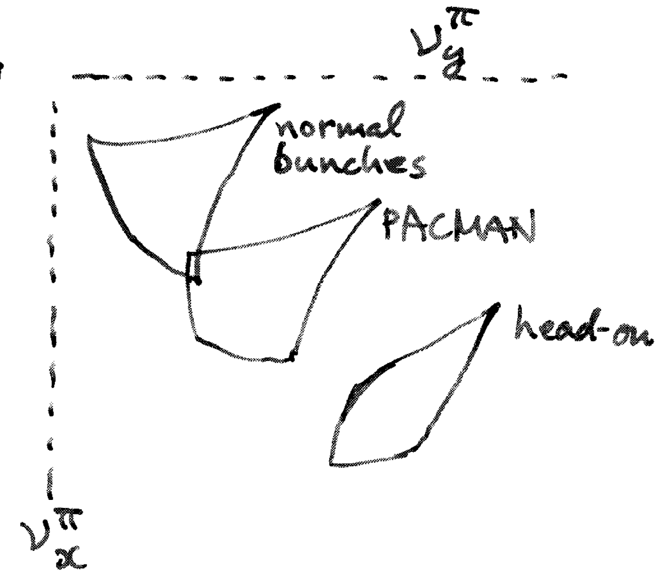
New LHC parameters
include all bunches

Decoherence .... can be relied on?

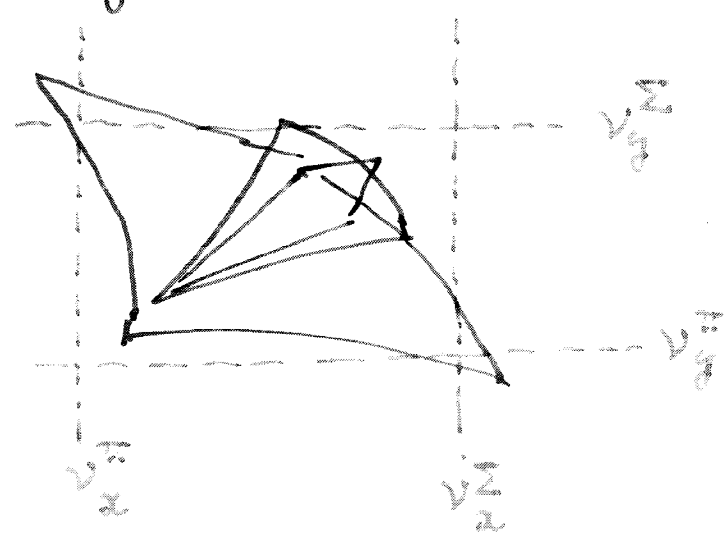
- Theory (or speculation)

$$\begin{cases} \Delta\nu_\pi = 2 \times (\text{incoherent tune shift}) \\ \Delta\nu_\Sigma = 0 \end{cases}$$

Horizontal crossing



Alternating crossing



- π-mode overlaps with footprint ?
- Cause Landau Damping ?

Too much uncertainty.

- More refined theory needed
- Realistic LHC parameters
- Strong-Strong simulation ?
  - Possible if a few bunches
  - Create a simple model
    with overlap
  - Parasitic collision needed ? for reallistic overlap.

Miscellaneous

- **Possible experiments at RHIC**
  - $\nu_1 \neq \nu_2$ effects   1 bunch × 1 bunch

    (Can be done at other machines too.)

    excite π-mode
    and observe damping

    ◎ Predictions needed
  - $\Delta x^*, \Delta y^*$ problem

    Must be at hadron machine

    Create $\Delta x^*, \Delta y^*$ artificially.

    Observe proton life
  - Feedback

    Test beam-beam responce function.

    feedback kick on one beam
    → observe the other.

    Must be hadron rings
- **Injection mode → Collision mode**
  - No serious problems presumably.
  - Can be tracked by PIC simulation if needed
    (not many bunches)